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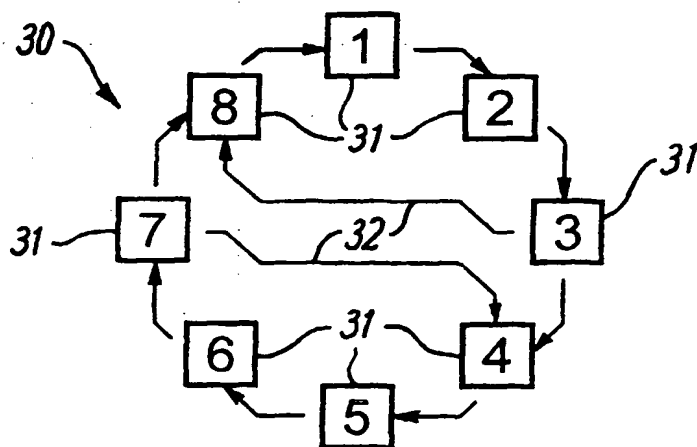
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(54) Title: PROCESSOR WITH LOAD BALANCING



(57) Abstract: The present invention relates to a system and method of distributing workload among processors (11) in a multi-processor system (10), with workload being transferred through a plurality of transfers between processor pairs (12), such that the plurality of pairs together define a closed loop. The present invention enables a processor to automatically balance its workload with other similar processors connected to it, with minimal interprocessor connection.

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06F9/50

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B. FIELDS SEARCHED

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Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GEHRKE J E ET AL: "Rapid convergence of a local load balancing algorithm for asynchronous rings" DISTRIBUTED ALGORITHMS. 11TH INTERNATIONAL WORKSHOP, WDAG '97. PROCEEDINGS, vol. 220, no. 1, 6 June 1999 (1999-06-06), pages 1-18, XP002200403 Theoretical Computer Science, Elsevier, Netherlands ISSN: 0304-3975	1-8
Y	page 1, line 1 -page 3, line 32	9-11
Y	US 5 031 089 A (LIU HOWARD T ET AL) 9 July 1991 (1991-07-09) abstract; figure 4	9-11
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☒ Further documents are listed in the continuation of box C.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>CORTES A ET AL: "On the performance of nearest-neighbors load balancing algorithms in parallel systems" PARALLEL AND DISTRIBUTED PROCESSING, 1999. PDP '99. PROCEEDINGS OF THE SEVENTH EUROMICRO WORKSHOP ON FUNCHAL, PORTUGAL 3-5 FEB. 1999, LOS ALAMITOS, CA, USA, IEEE COMPUT. SOC, US, 3 February 1999 (1999-02-03), pages 170-177, XP010321821 ISBN: 0-7695-0059-5 page 172, right-hand column, line 1 -page 173, left-hand column, line 21</p>	1-11
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A	<p>EP 0 756 233 A (TAO GROUP LTD) 29 January 1997 (1997-01-29) page 3, line 51 -page 4, line 38</p>	1,7
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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1 Processor with load balancing

2

3 The present invention relates to a system intended for
4 use in multi-processor computers and in particular to
5 work load balancing in dataflow parallel computers.

6

7 Multi-processor computers are used to execute programs
8 that can utilise parallelism, with concurrent work being
9 distributed across the processors to improve execution
10 speeds.

11

12 The dataflow model is convenient for parallel execution,
13 having execution of an instruction either on data
14 availability or on data demand, not because it is the
15 next instruction in a list. This also implies that the
16 order of execution of operations is irrelevant,
17 indeterminate and cannot be relied upon. The dataflow
18 model is also convenient for parallel execution because
19 tokens may flow to specified instructions rather than
20 having the data stored in a register or memory
21 potentially accessible by all other instructions.

22

23 In multithreaded dataflow, memory may be introduced into
24 the flow of tokens to instructions. Only one token is
25 required to trigger execution of an instruction, the
26 second operand being fetched from the memory when the
27 instruction is issued or executed (Coleman, J.N.; A High
28 Speed Dataflow Processing Element and Its Performance
29 Compared to a von Neumann Mainframe, Proc. 7th IEEE
30 International Parallel Processing Symposium, California,
31 pp.24-33, 1993 and Papadopoulos, G.M.; Traub, K.R.;
32 Multithreading: A Revisionist View of Dataflow
33 Architectures, Ann. Int. Symp. Comp. Arch., pp.342-351,

1 1991). The result is passed along an arc to initiate a
2 new instruction and optionally written back to memory.
3 The memory makes it difficult to avoid side-effects in
4 hardware, but their problems can be avoided in software
5 through suitable programming discipline. This
6 modification of the dataflow model overcomes some of the
7 physical and speed difficulties of other solutions. In
8 particular it removes the need for hardware token
9 matching. As the smallest element that can be
10 parallelised is a thread, rather than an instruction, the
11 number of times that the token matching need be performed
12 is much reduced and so the overheads incurred in
13 performing the operation in software can be justified.

14
15 Load balancing in a multi-processor computer has the aim
16 of ensuring every processor performs an equal amount of
17 work. This is important for maximising computational
18 speeds. Traditionally, multi-processor computers have
19 required complicated hardware or software to perform this
20 task, and the configuration (i.e., interconnection) of
21 the processors and memories need to be taken into
22 account. The load balancing mechanism has greatest
23 performance restricting effect during times of explosive
24 parallelism. It must be able to transfer loads
25 throughout the system quickly, in order to maintain a
26 higher overall efficiency.

27
28 Traditional methods of load balancing require expensive
29 networks and complicated load analysis, and static off-
30 line scheduling has been used to solve the problem (this
31 entails analysing the program before it is run to find
32 out what resources it needs, when, and scheduling all
33 tasks prior to running).

1

2 On-line load balancing is difficult because of the
3 complexity and cost in the networks involved. For
4 example, in a system containing 100 processors, load
5 balancing potentially requires not only a check of all
6 100 processors to find out which are free to do work, but
7 also consideration of which piece of work is best suited
8 to each processor, depending on what is already scheduled
9 for that processor. If pieces of work differ in size
10 then care must be taken to ensure that work is evenly
11 distributed.

12

13 The difficulty in balancing load is proportional to the
14 square of the number of processors. If it is decided
15 that all work must be scheduled within a fixed amount
16 time, even under the worst case conditions, then because
17 work can originate anywhere and be scheduled to any
18 destination, it is necessary to have a network with a
19 band width proportional to N^2 where N is the number of
20 processors. This means that a system with one thousand
21 processors is ten thousand times more complicated and
22 costly than a system with only ten processors, despite
23 having only one hundred times the power. It is desirable
24 to have a system where complexity and cost are
25 proportional only to N , even under worst case conditions.

26

27 In the prior art inventions are known which provide
28 systems for load balancing in multi-processor computer
29 systems. US Patent 5,630,129 to Sandia Corporation
30 describes an application level method for dynamically
31 maintaining global load balance on a parallel computer.
32 Global load balancing is achieved by overlapping

1 neighbourhoods of processors, where each neighbourhood
2 performs local load balancing.

3

4 US Patent 5,701,482 to Hughes Aircraft Company describes
5 a modular array processor architecture with a control bus
6 used to keep track of available resources throughout the
7 architecture under control of a scheduling algorithm that
8 reallocates tasks to available processors based on a set
9 of heuristic rules to achieve the load balancing.

10

11 US Patent 5,898,870 to Hitachi, Ltd. describes a load
12 sharing method of a parallel computer system which sets
13 resource utilisation target values by work for the
14 computers in a computer group. Newly requested work
15 processes are allocated to computers in the computer
16 group on the basis of the differences between the
17 resource utilisation target parameter values and current
18 values of a parameter indicating the resource
19 utilisation.

20

21 It is an object of the present invention to provide a
22 processor which can automatically balance its workload
23 with other similar processors connected to it.

24

25 According to the first aspect of this invention, there is
26 provided a multi-processor system comprising a plurality
27 of processors, a plurality of comparison means for
28 comparing the load at a pair of processors and a
29 plurality of load balancing means responsive to the
30 comparison means for passing workload between the said
31 pair of processors, characterised in that the plurality
32 of load balancing means defines a closed loop around
33 which workload can be passed.

1

2 Preferably the passing of workload is uni-directional
3 around the closed loop.

4

5 More preferably, the passing of workload comprises the
6 passing of a processing thread.

7

8 Preferably the passing of a processor thread comprises
9 the passing of an instruction.

10

11 Preferably the passing of an instruction comprises the
12 passing of an instruction and the pointer to the context
13 of said instruction.

14

15 According to a second aspect of this invention, there is
16 provide a method of distributing load among processors in
17 a multi-processor system. The method comprising the
18 steps of:

- 19 • comparing the load in pairs of processors and
20 • transferring workload between said processors
21 characterised in that the workload is transferred through
22 a plurality of transfers between pairs, such that the
23 plurality of pairs together define a closed loop.

24

25 Preferably, the pairs in the closed loop comprising a
26 first processor and a second processor, the first
27 processor informs the second processor of the first
28 processor's workload.

29

30 Preferably, the second processor compares the first
31 processor's workload with its own workload.

32

1 More preferably, the second processor determines whether
2 it will request more work from the first processor.

3

4 Preferably, the second processor requests work from the
5 first processor.

6

7 Optionally, comparison means for comparing the load of
8 two processors and load balancing means responsive to the
9 comparison means can be introduced cutting across the
10 loop to accelerate load balancing around the loop.

11

12 The load balancing means responsive to the comparison
13 means ensure that between every pair there is a balance
14 of workload, and a closed loop ensures that every
15 processor in every pair is downstream of another
16 processor, which in turn ensures that the entire loop is
17 inherently balanced with respect to workload.

18

19 With a bi-directional link between the first and second
20 processor, both processors in a pair inform each other of
21 workload and request work as appropriate. There is no
22 requirement for such pairs to be arranged in a circle.

23

24 When work is requested from a processor, preferably that
25 processor picks up a suitable instruction out of its
26 pipeline, and transfers that instruction and its context
27 (e.g., data tokens on input/output arcs) across to the
28 requesting processor which then inserts it directly into
29 its own pipeline. This is possible because each
30 instruction is an independent unit of work within each
31 processor, and therefore within the system as a whole.

32

1 In order to provide a better understanding of the present
2 invention an example will now be described, by way of
3 example only, and with reference to the accompanying
4 Figures, in which :

5

6 Figures 1 to 3 illustrate configurations of the
7 processors and workflow in the system of the present
8 invention

9

10 Figure 4 illustrates a block diagram of the system
11 including processors and memory

12

13 Figure 5 illustrates thread transfer between a pair
14 of processors

15

16 The invention is a multi-processor dataflow computer
17 which functions to balance workload between the
18 processors.

19

20 Although the embodiments of the invention described with
21 reference to the drawings comprise computer apparatus and
22 processes performed in computer apparatus, the invention
23 also extends to computer programs, particularly computer
24 programs on or in a carrier, adapted for putting the
25 invention into practice. The program may be in the form
26 of source code, object code, a code of intermediate
27 source and object code such as in partially compiled form
28 suitable for use in the implementation of the processes
29 according to the invention. The carrier may be any
30 entity or device capable of carrying the program.

31

32 For example, the carrier may comprise a storage medium,
33 such as ROM, for example a CD ROM or a semiconductor ROM,

1 or a magnetic recording medium, for example, floppy disc
2 or hard disc. Further, the carrier may be a
3 transmissible carrier such as an electrical or optical
4 signal which may be conveyed via electrical or optical
5 cable or by radio or other means.

6
7 When the program is embodied in a signal which may be
8 conveyed directly by a cable or other device or means,
9 the carrier may be constituted by such cable or other
10 device or means.

11
12 Alternatively, the carrier may be an integrated circuit
13 in which the program is embedded, the integrated circuit
14 being adapted for performing, or for use in the
15 performance of, the relevant processes.

16
17 Referring firstly to Figure 1, a closed loop 10 of
18 processors 11 are connected by link means 12. Preferably
19 the link means comprises connection through an electrical
20 circuit or a packet switched network. The link means
21 provide the means for comparison of workload and passing
22 of workload between processors. In Figure 1 the link
23 means 10 are uni-directional, wherein the transfer of
24 workload through the link means is in one direction.
25 With a uni-directional link from processor A 13
26 ("upstream") to processor B 14 ("downstream"), A informs
27 B of how much workload it has, B then compares this with
28 its own level of workload, and if B is less loaded than
29 A, then it requests work from A. It is therefore ensured
30 that B has at least as much work as A. Such pairs are
31 linked end to end in a chain, with all the links going in
32 the same direction, with the ends of the chain joined
33 together. This forms a closed loop with all the workload

1 transfers travelling in the same direction. Since in
2 each pair the one downstream of the link has at least as
3 much work as the one upstream, and every processor in
4 every pair downstream of another processor, it ensures
5 that the entire ring is inherently balanced.

6

7 Referring to Figure 2, a closed loop 20 of processors 21
8 with bi-directional link means 22 is shown, wherein the
9 transfer of workload through the link means between each
10 processor pair is in one direction. The two processors in
11 a pair both inform each other and request workload as
12 appropriate.

13

14 Referring to Figure 3, a closed loop 30 of processors 31
15 is shown with additional links 32 between pairs cutting
16 across the ring, which have been introduced to accelerate
17 load balancing around the ring.

18

19 Referring to Figure 4, a block diagram of a multi-
20 processor system 40 is shown, which is a shared memory
21 multi-processor dataflow computer. The three main
22 components are processors 41, crossbar switches 42 for
23 providing the means for relaying memory requests from
24 processors to memory controllers, and memory controllers
25 43. We envisage these component being implemented on
26 separate chips and connected accordingly. Preferably,
27 the processors are connected in a uni-directional
28 circular pipeline or closed loop, and access is set as
29 interleaved memory modules through a crossbar switch
30 array. Preferably processors issue memory requests to
31 the crossbar switches, which then relay them to the
32 memory leaves. Memory controllers return the result of
33 the request back to the processors via the crossbar

1 switches. Preferably all communication is handled
2 automatically in hardware. Preferably, inter-processor
3 communication is invisible to the programmer and program
4 and preferably comprises load balancing traffic.
5 Transactions allow several memory accesses to be
6 performed concurrently; the processor can send out a
7 stream of requests, those that go back to different
8 crossbar switches will be handled simultaneously, and the
9 results will stream back. This reduces rather than just
10 hides the memory latency, but it is dependent on all
11 memory leaves being evenly utilised.

12
13 Each processor keeps track of how many threads it is
14 hosting at any one time. It passes this information on
15 to the next processor round the closed loop. This means
16 that each processor can determine its own load, as well
17 as the load of its predecessor. By comparing the two
18 loads, a load imbalance can be calculated. If this is
19 outside tolerances (e.g., greater than one thread
20 difference), then the processor may request load from its
21 predecessor.

22
23 Referring to Figure 5, a thread transfer between a pair
24 of processors 50 is shown. Upon receiving a request for
25 a load, preferably a processor's 51 multiplexer stage 52
26 will pick out the next passing eligible instruction and
27 route it out of the input/output unit, IO unit 53.
28 Preferably, the IO unit 53 comprises a shift register
29 which transfers the instruction and its flow operands out
30 to the requesting processor 54 over a thread transfer bus
31 55. Preferably, the requesting processor 54 accumulates
32 the transmission in its own IO unit 56 and, when this
33 shift register is full, the register contents are passed

1 to the multiplexer 57, which then merges it into the
2 pipeline flow. Preferably, this activity is entirely
3 invisible to the program.

4

5 Further modification and improvements may be added
6 without departing from the scope of the invention herein
7 described.

8

1 Claims

2

3 1. A multi-processor system comprising a plurality of
4 processors, a plurality of comparison means for
5 comparing the load at a pair of processors, and a
6 plurality of load balancing means responsive to the
7 comparison means for passing workload between said
8 pair of processors, characterised in that the
9 plurality of load balancing means defines a closed
10 loop around which workload can be passed.

11

12 2. A system as claimed in claim 1 wherein the passing
13 of workload is uni-directional around the closed
14 loop.

15

16 3. A system as claimed in claims 1 to 2 wherein the
17 passing of workload comprises the passing of a
18 processing thread.

19

20 4. A system as claimed in claim 3 wherein the passing
21 of a processing thread comprises the passing of an
22 instruction.

23

24 5. A system as claimed in claim 4 wherein the passing
25 of an instruction comprises the passing of an
26 instruction and a pointer to the context of said
27 instruction.

28

29 6. A system as claimed in claims 1 to 5 wherein there
30 are load balancing means responsive to comparison
31 means comparing the load of a pair of processors in
32 the closed loop of claim 1, the said pair of
33 processors not being compared in claim 1.

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7. A method for distributing load among processors in a multi-processor system, the method comprising the steps of:

Comparing the load in pairs of processors and

Transferring work load between said processors

characterised in that the workload is transferred through a plurality of transfers between pairs of processors, such that the plurality of pairs together define a closed loop.

8. A method as claimed in claim 7 wherein the pairs comprise a first processor and a second processor, and first processor informs the second processor of the first processor's work load.

9. A method as claimed in claim 8 wherein the second processor compares the first processor's work load with its own work load.

10. A method as claimed in claims 8 to 9 wherein the second processor determines whether it will request more work from the first processor.

11. A method as claimed in claims 8 to 10 wherein the second processor requests work from the first processor.

$\frac{1}{2}$

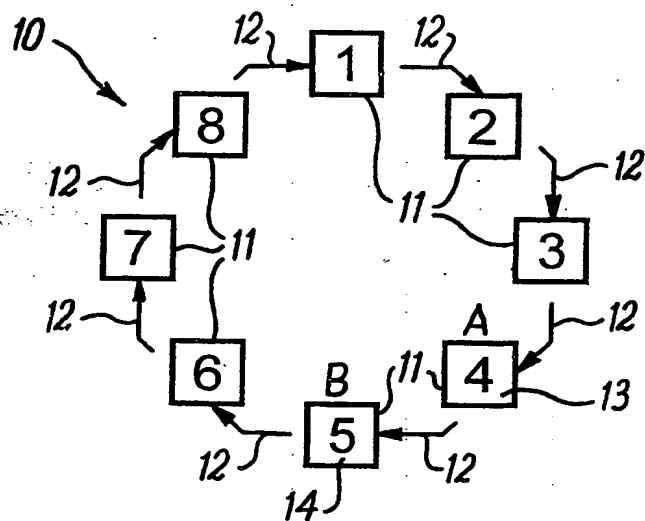


FIG. 1

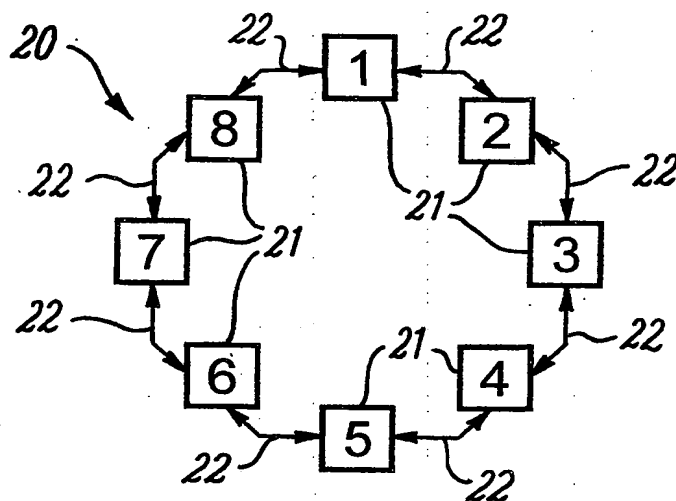


FIG. 2

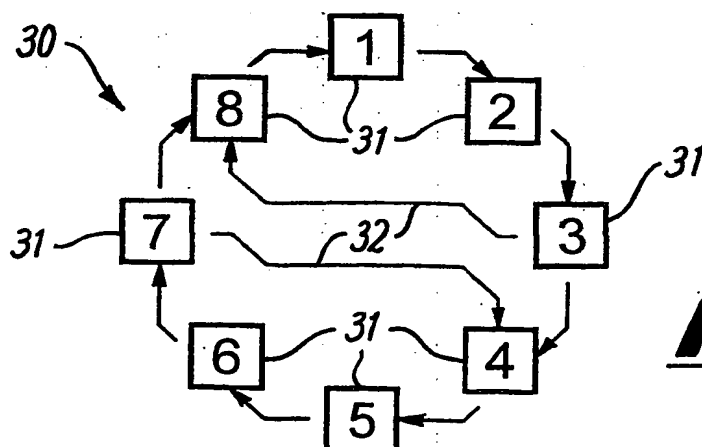
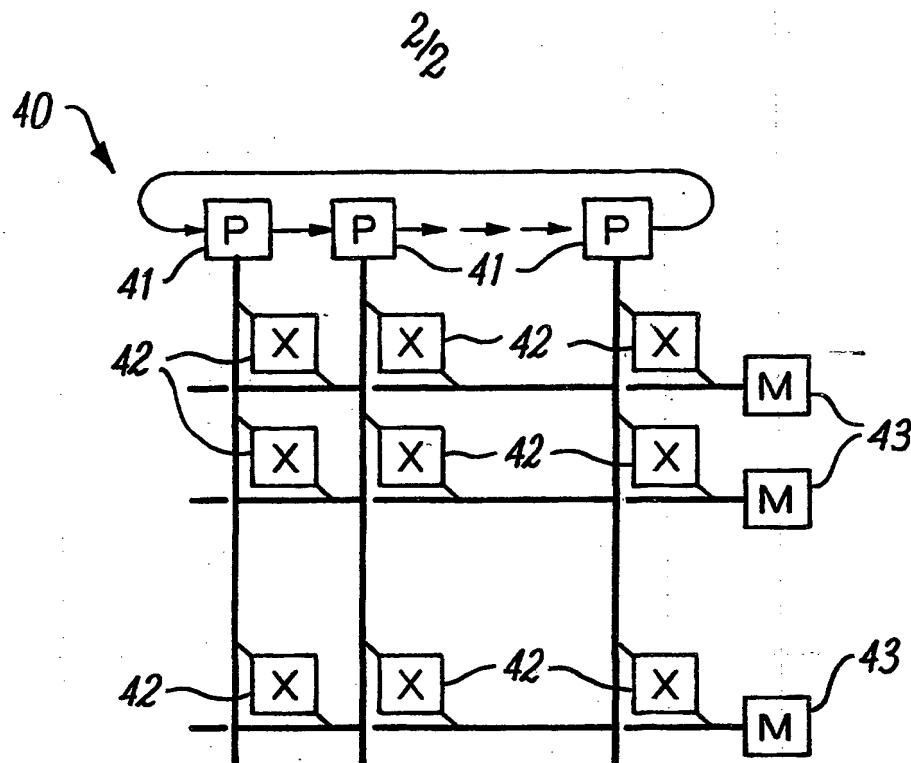
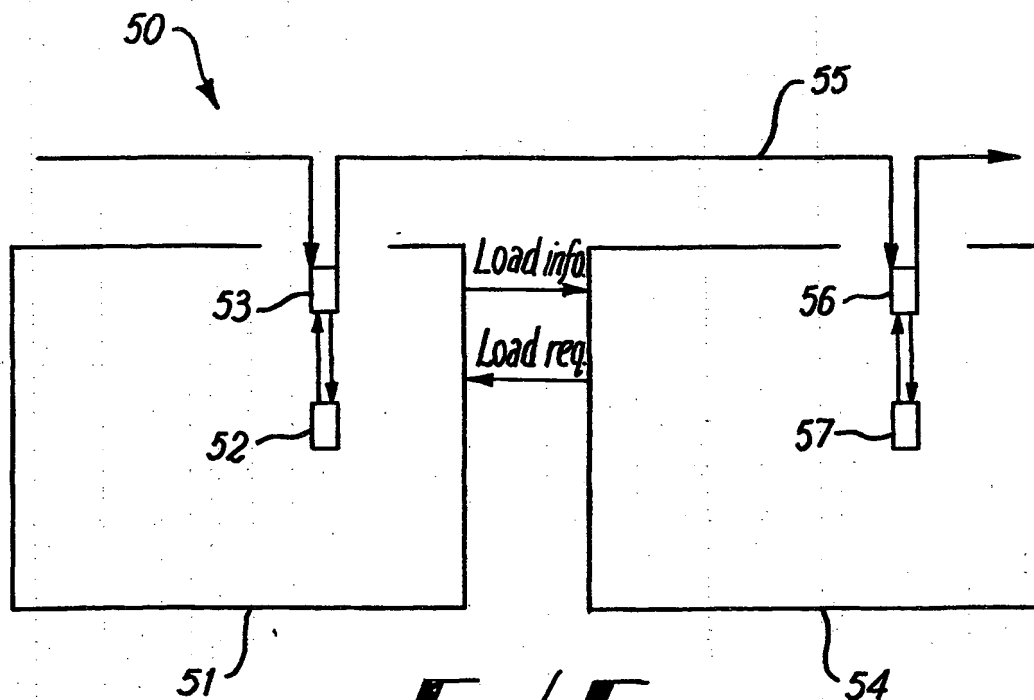


FIG. 3

**FIG. 4****FIG. 5**